Mission Automation for "A Train" Correlative Measurements

Mark Abramson, David Carter, Brian Collins, Stephan Kolitz, Pete Scheidler, Charles Strauss
The Charles Stark Draper Laboratory, Inc.
Cambridge, MA 02139

Abstract– **We have enhanced Draper Lab's Earth Phenomena Observing System testbed to utilize near-real-time cloud cover data from the Air Force Weather Agency's Joint Army Air Force Weather Information Network World-Wide Merged Cloud Analysis. The cloud data is used as input in the simulated tasking of the TES and HIRDLS instruments on Aura, with the objective of achieving increased science value of the observation data. The cloud cover data includes 1) hourly updates of current conditions and 2) forecast updates provided every six hours for up to 30 hours in the future. The cloud cover contains information on up to four cloud layers for each of 1024 x 1024 cells per hemisphere specified in a polar stereographic grid. We describe models we have developed of the observation-taking processes used by Aura's HIRDLS and TES instruments. We model each HIRDLS mode as a fixed scan pattern, i.e., a sequence of azimuth and elevation values. We model TES as a scan of a ground area, using a latitude and longitude viewpoint. We calculate the science value of sensor observations as a function of the target, the sensor line of sight and field of view, and the cloud cover. The observation science value function is used as input in the optimization-based planning function of the EPOS mission planner, which generates plans that could be used in HIRDLS' Selected Targets Mode and TES' Special Product Mode. These modes could be invoked during times the instruments are not in standard collection modes, e.g., HIRDLS' Global Observing Mode and TES' Global Survey Mode.**

I. Introduction

We have enhanced Draper Lab's Earth Phenomena Observing System (EPOS) testbed to utilize near-real-time cloud cover data from the Air Force Weather Agency's (AFWA – at Offutt AFB) Joint Army Air Force Weather Information Network (JAAWIN) World-Wide Merged Cloud Analysis. The cloud data is used as input in the simulated tasking of the TES and HIRDLS instruments on Aura, with the objective of achieving increased science value of the observation data.

II. Operational Concept

This section describes the imagined operational concept in which EPOS would be applied. We assume there is a ground facility for each Aura sensor (TES, HIRDLS) through which all observation requests (e.g., targets – locations on or above the surface of the Earth – and associated sensor and observation parameters) from scientists are processed and prioritized. EPOS translates these prioritized requests into an observation value function over the relevant set of times and targets. Forecasts of cloud coverage are developed from the AFWA JAAWIN World-Wide Merged Cloud Analysis. Finally, constraints on the operational modes over the planning period are specified for use in EPOS. The EPOS Mission Manager performs dynamic retasking, i.e., it replans the sensor observation schedule based on the latest near-real-time information, e.g., cloud cover forecasts, producing sensor moding and tasking commands that could be included in the Aura command stream. Example TES decisions include which mode to be in at what time, and if in tasking mode, which target to point. Example HIRDLS decisions include which mode to be in at what time, and if in selected targets mode, what the azimuth line of sight should be, along with the elevation scan rate and range.

We are planning to evaluate the potential benefits of utilizing EPOS in such an operational concept, and in other related operational concepts that will be developed.

III. JAAWIN Cloud Data

We use data provided by AFWA's JAAWIN World Wide Merged Cloud Analysis for cloud cover forecasting and decision-making in EPOS. The JAAWIN data is fused from cloud data from five geosynchronous and four polar orbiting satellites. Worldwide current cloud estimates are generated hourly by the Cloud Depiction and Forecast System II (CDFS II). Cloud amounts and types are analyzed for four floating layers. Cloud amounts are expressed in percentages to the nearest 1% with layer tops and bases in meters above mean sea level. The data is provided in polar-stereographic grids of 1024 by 1024 for each hemisphere with cells having a rectangular dimension of approximately 24 km at ±60° latitude. For each volume element, the data includes:

- Four layers of percent cloud coverage
- Four layers of cloud type
- Four layer cloud top heights
- Four layer cloud bottom heights
- Total cloud amount in percent
- Time information for each pixel.

Figure 1 illustrates three cells with views from the side, with altitude on the vertical axis.

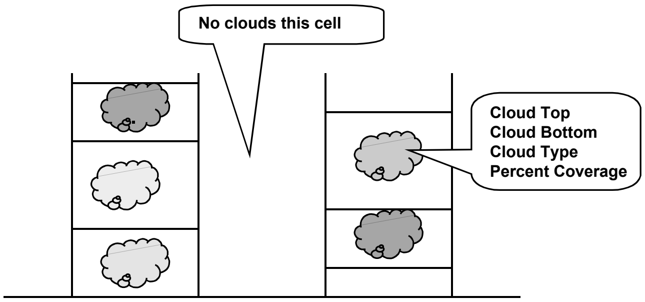


Figure 1: Side View of Three Grid Cells

Forecasts are provided every six hours, with hourly forecasts for 1-30 hours into the future.

The data is provided in a well-documented format used in the Meteorological community: GRIB or gridded binary. Each data set is ~22 mb and the download from the JAAWIN web site takes 4 minutes using half a T1 line.

Every hour at quarter past the hour, we interrogate the AFWA JAAWIN server at Offutt Air Force Base. New forecasts and new current weather state information are downloaded and stored data locally in a database system (the EPOS Cloud Server). We have tested this capability over multiple days and have successfully obtained all forecasts and current state estimates.

Figures 2, 3 and 4 illustrate cloud data visualized in our software.

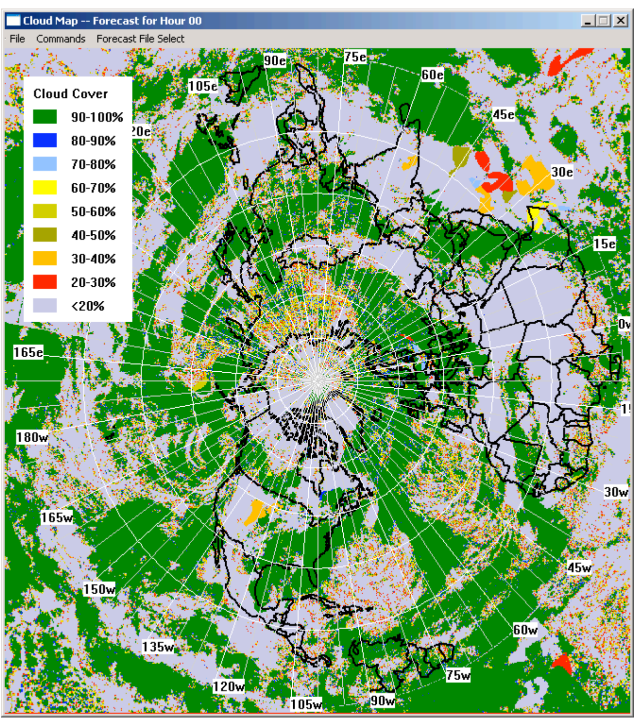


Figure 2: North Polar Stereographic View of Cloud Data

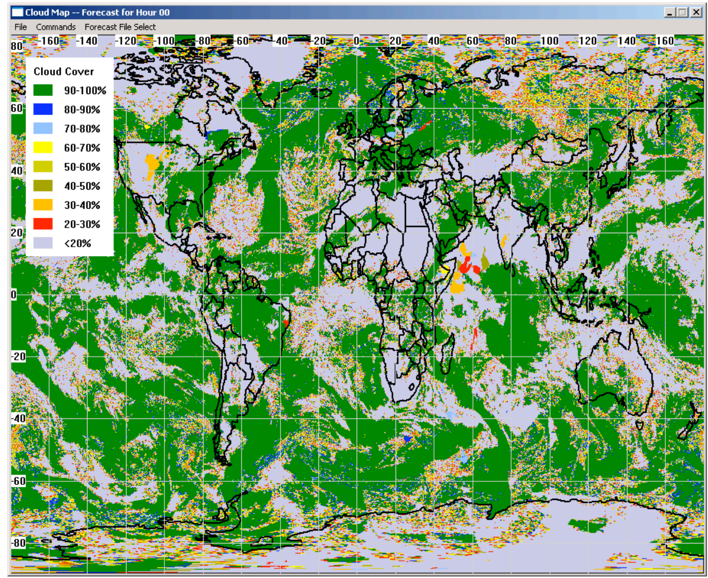


Figure 3: Latitude/Longitude View of Cloud Data

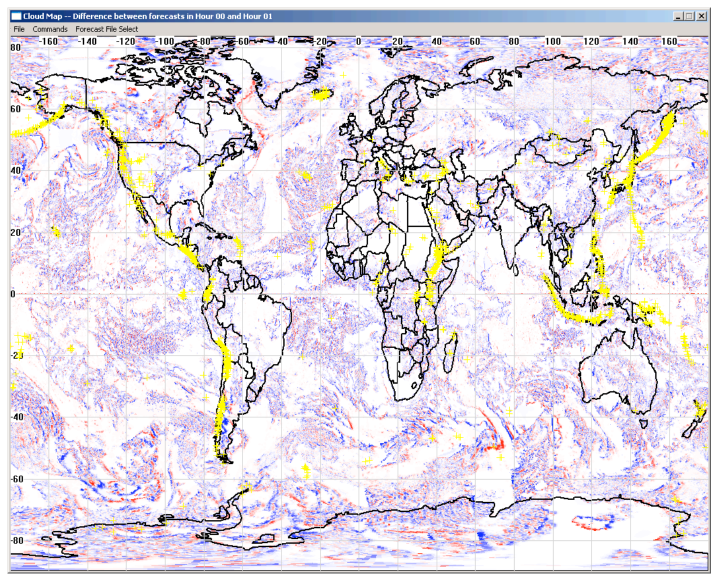


Figure 4: Current and Corresponding One Hour Forecast Data Comparison
White = clouds unchanged, Blue = decreasing cloudiness, Red =increasing cloudiness, Yellow = volcano locations

IV. SENSOR MODELING

A. HIRDLS

Each HIRDLS observing mode is modeled by a fixed scan pattern consisting of sequences of azimuth and elevation values. The Global Observing Mode consists of 6 vertical scans, at azimuths which correspond to 5° separation in the cross-track direction. Each vertical scan covers about 3° of elevation and takes approximately 10 seconds. Inflight calibration is included in the scan and each instance requires approximately 66 seconds total.

A number of other modes are also modeled as a fixed scan pattern in azimuth and elevation, including: Alternative Global Observing Mode, Fine Horizontal Spacing Modes, and Gravity Wave Mode. One that is of particular interest is the Selected Targets Mode, consisting of an elevation scan over a fixed geographic location (e.g., volcano).

The functional description of the HIRDLS model was implemented in MATLAB as a prototype, prior to integration within EPOS in C++, is illustrated in Figure 5.

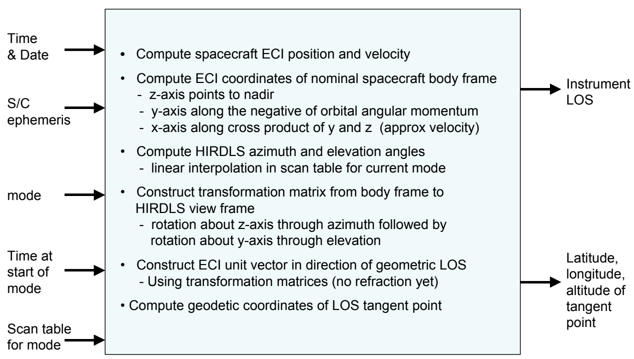
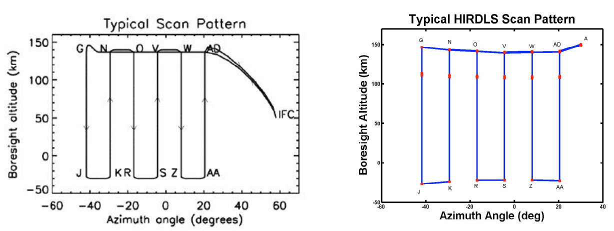


Figure 5: Functional Description of HIRDLS Model

Fgure 6 illustrates a Global Observing Mode scan pattern taken from ATBD-HIR-01[1], pages 6-7, and output generated by our MATLAB HIRDLS model. Figure 7 shows the plots from our HIRDLS model of a variety of other variables of interest.



Taken from ATBD-HIR-01, pp. 6-7 Generated by HIRDLS model (MATLAB)

Figure 6: HIRDLS Model Comparison

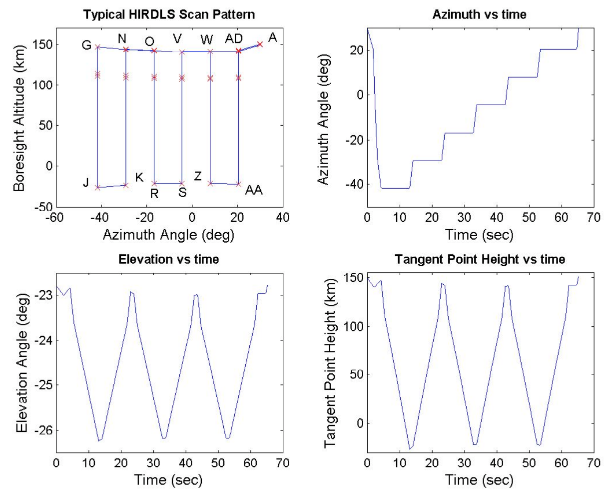


Figure 7: HIRDLS Model Results

B. TES

TES operates in two primary modes. TES standard products are generated in Global Survey Mode. In this mode, it makes continuous sets of nadir and limb observations (plus calibrations) on a 20 orbits on, 9 orbits off cycle. The other primary mode is Special Observation Mode. During the "off" days, TES is not actually powered down. These are the times for making extensive calibrations and for the Special Product modes: observations of e.g., volcanoes, biomass burning, pollution events, and intercomparisons. The sensor is pointable in this mode within 45° of nadir (cross-track and in-track). Almost everywhere on Earth can be reached some time during a 16 day interval.

In TES Global Survey Mode, TES obtains its data using sequences of 2 nadir observations (4 sec each), 3 limb observations (16 sec each), and 3 calibration periods (4 sec each). Each sequence requires 81.2 seconds (including slews). This is illustrated in Figure 8[2]. The basic sequence is repeated continuously for 20 orbits.

[1] High Resolution Dynamics Limb Sounder, Algorithm Theoretical Basis Document, ATBD-HIR-01/SW-HIR-168, 10/4/1999, http://www.atm.ox.ac.uk/user/wells/atbd.html

[2] For Figures 8 and 9 see: Tropospheric Emission Spectrometer for the Earth Observing System's Aura satellite, R. Beer, T. Glavich, D. Rider, Applied Optics vol. 40, no. 15, 5/20/2001, pp. 2356-2367

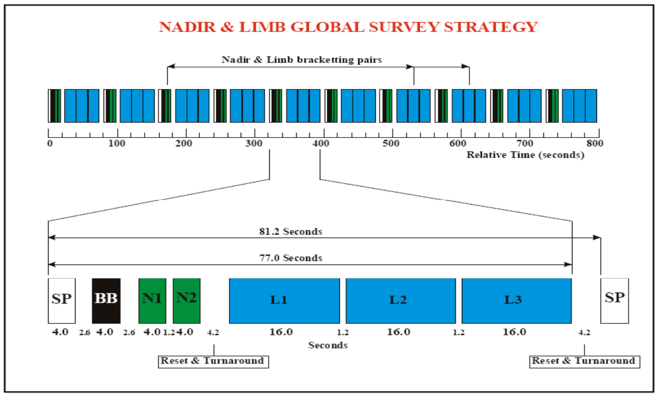


Figure 8: Global Survey Observation Sequence

The pairs of nadir observations in each sequence are co-located and the limb observations correspond geographically to nadir observations made 437 seconds earlier. This data will be combined into observation sets containing collocated limb and nadir observations. Each observation set will then be analyzed as a unit [ATBD-TES-01[3], p. 5].

Global Surveys are triggered by the time of crossing of the Southern Apex, so observations are made at the same latitudes during each orbit. This is illustrated in Figure 9.

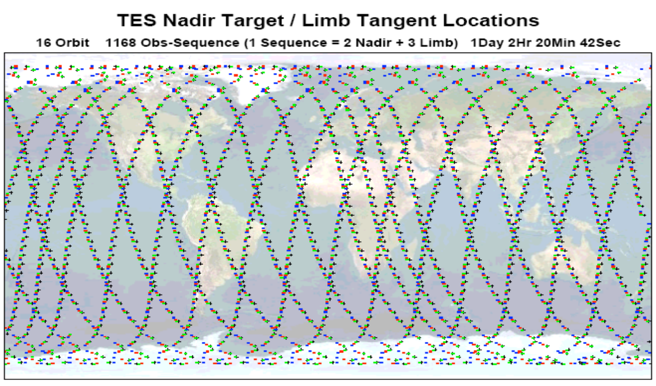


Figure 9: TES Observation Points

We model TES Global Survey mode as a scan in viewpoint latitude and longitude. This is consistent with planning operations, and reduces the computational load from what it would be if we used a model similar to the HIRDLS model.

C. LOS/FOV VALUE CALCULATION

We use the cloud data as input in the calculation of the value of observations with a given line of sight/field of view (LOS/FOV). For limb observations, the LOS intersects a number of cloud cells. Figure 10 illustrates this. The height of the cloud layers is less than 20 km and is represented by the green curve, with a distance above the blue curve, the Earth's surface, exaggerated for display. The distance the LOS passes through the atmosphere is denoted by ℓ and is approximately 350 km. At 60° latitude, this translated into approximately 15 cells that are traversed.

We are developing appropriate value functions based on the LOS/FOV through cloud data to be used as input in the optimization-based planning of sensor observations. Implementation of value function in software will have a number of aspects: a geometric aspect, which concerns location of the satellite and location of the instrument LOS/FOV; a ray-tracing aspect, which concerns accounting for predicted cloud density along the instrument line of sight; and a geographic information systems aspect, which concerns determining which targets are inside the LOS/FOV. In addition, the value function capture the scientific value of targets, as prioritized by scientists.

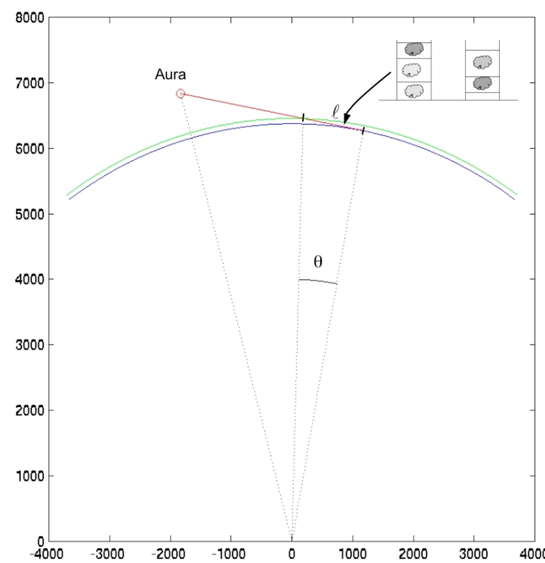


Figure 10: The View of the Limb through the Atmosphere

---

[3] Tropospheric Emission Spectrometer (TES) Level 1B Algorithm Theoretical Basis Document, version 1.1, H. Worden, K. Bowman, ATBD-TES-01/JPL D-16479, 9/30/1999, http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd/viewInstrument.php?instrument=TES

V. EPOS DEVELOPMENT

We are modifying the software design of EPOS to better handle operational concepts like the one described previously. There are five software components in EPOS, as illustrated in Figure 11.

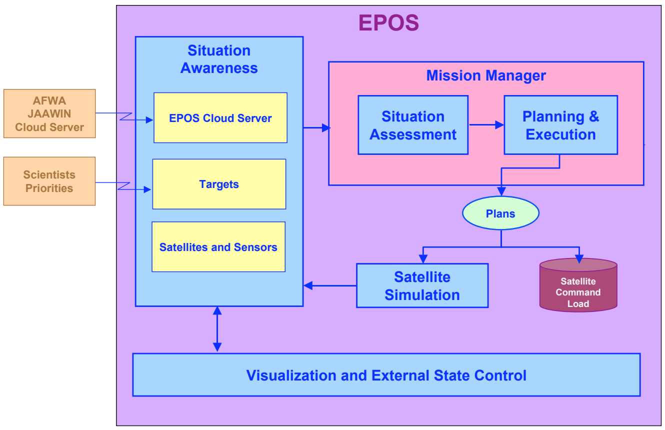


Figure 11: EPOS 4.0 System Architecture

- **Situation Awareness.** Situation Awareness of the state of the world occurs through External State Servers. These servers are queried by Situation Assessment. One of the external state servers is the USAF JAAWIN cloud server; it is accessed through the EPOS Cloud Server.
- **Situation Assessment.** Situation assessment propagates satellites, identifies candidate targets, and generates a target-value table that will be used by Planning and Execution. Situation Assessment queries Situation Awareness.
- **Planning and Execution**. Planning and Execution generates the plan from information passed by Situation Assessment and passes the plan appropriately to the simulation or a real-world system.
- **Satellite Simulation**. Satellite Simulation executes the plan and in turn updates the external state.
- **Visualization and External State Control.** Visualization and External State Control will be used by the user to monitor the progress of the simulation and to modify the external state in Situation Awareness.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Aeronautics and Space Administration's AIST program, under Contract #NAS5-03121, through the Goddard Space Flight Center. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.